The XENON Dark Matter Experiment

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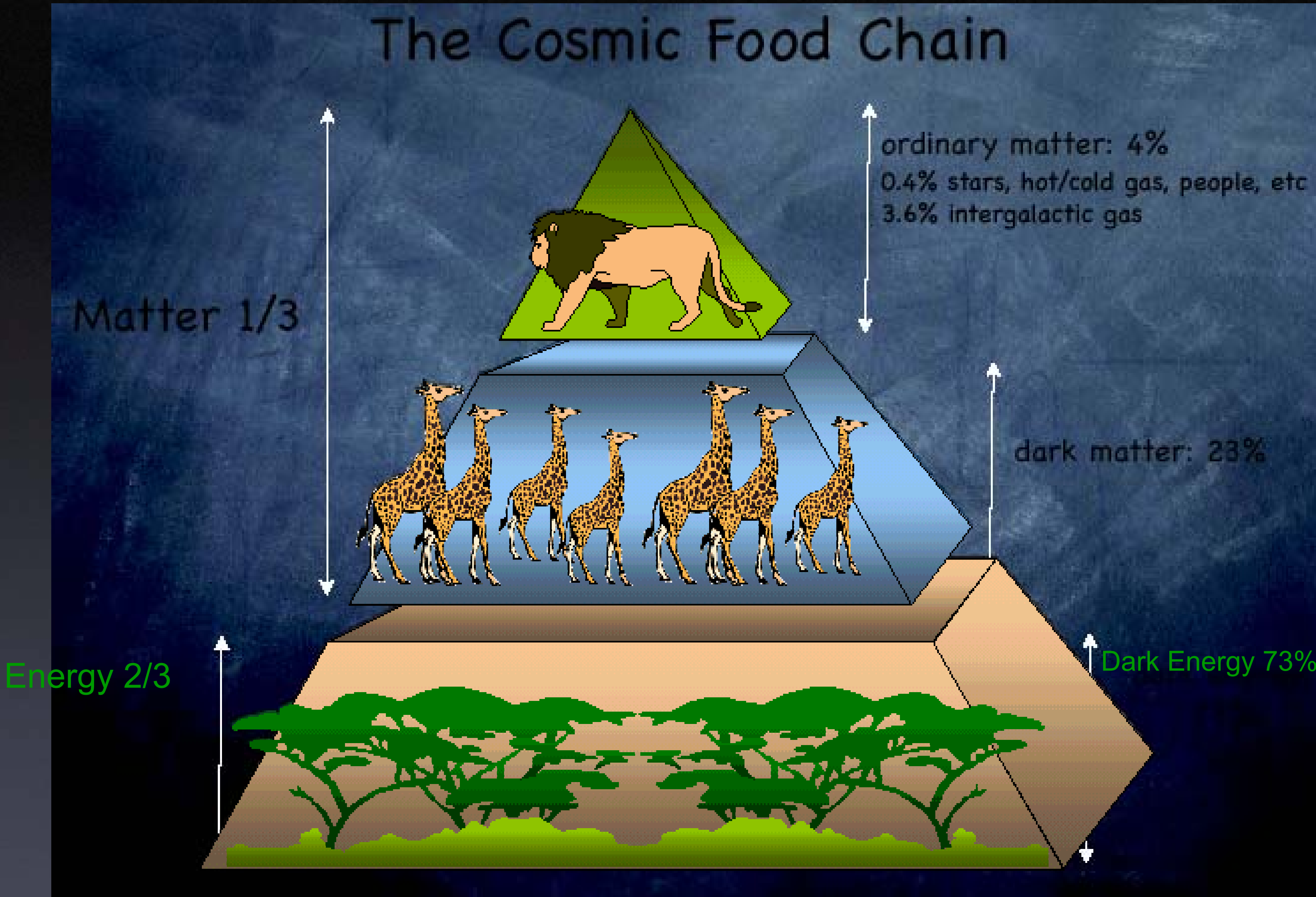
Columbia University

http://www.astro.columbia.edu/~lxe/XENON/

Xe

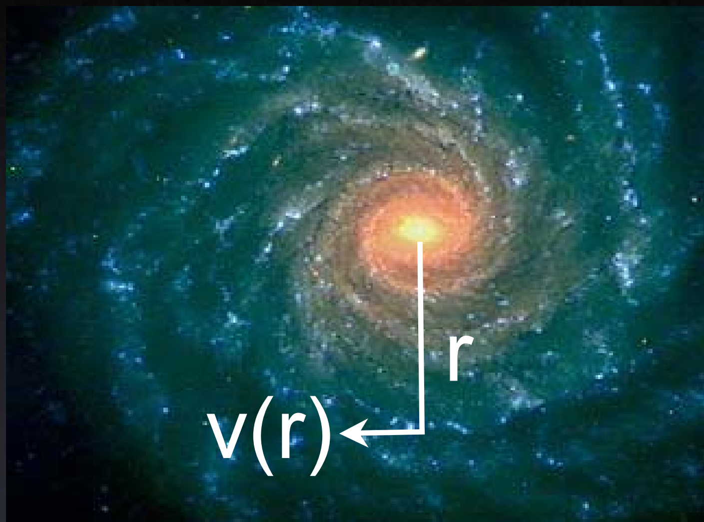
XENON

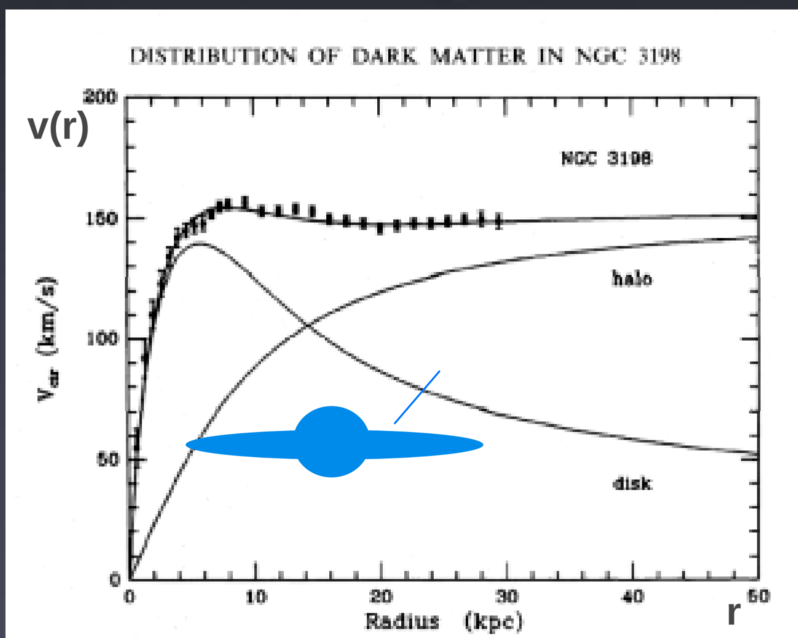
Dark Matter Project


The Cosmic Food Chain
Matter 1/3
ordinary matter: 4%
0.4% stars, hot/cold gas, people, etc
3.6% intergalactic gas
dark matter: 23%
Energy 2/3
Dark Energy 73%

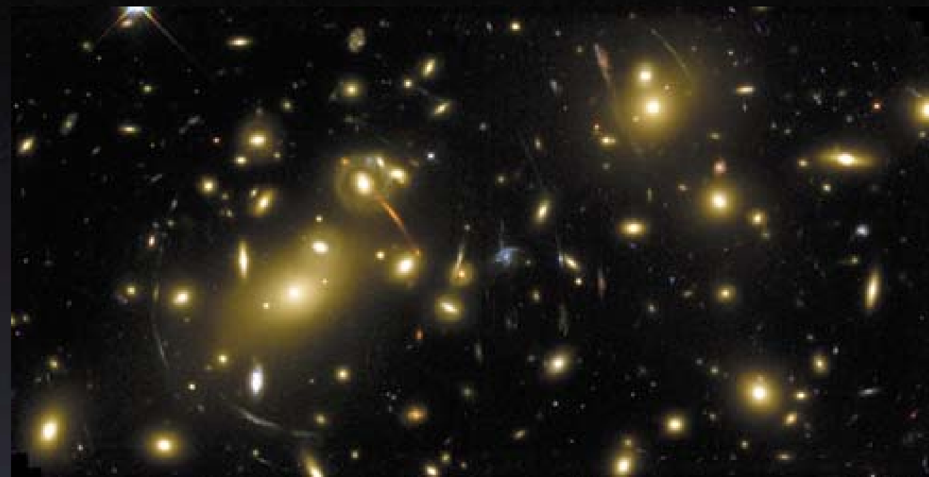
Evidence for dark matter

Rotation curves of spiral galaxies

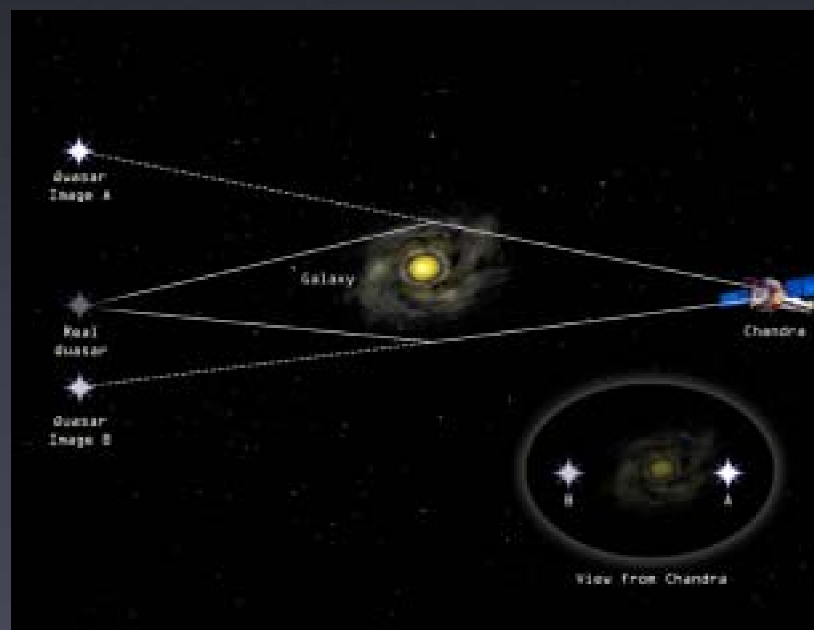




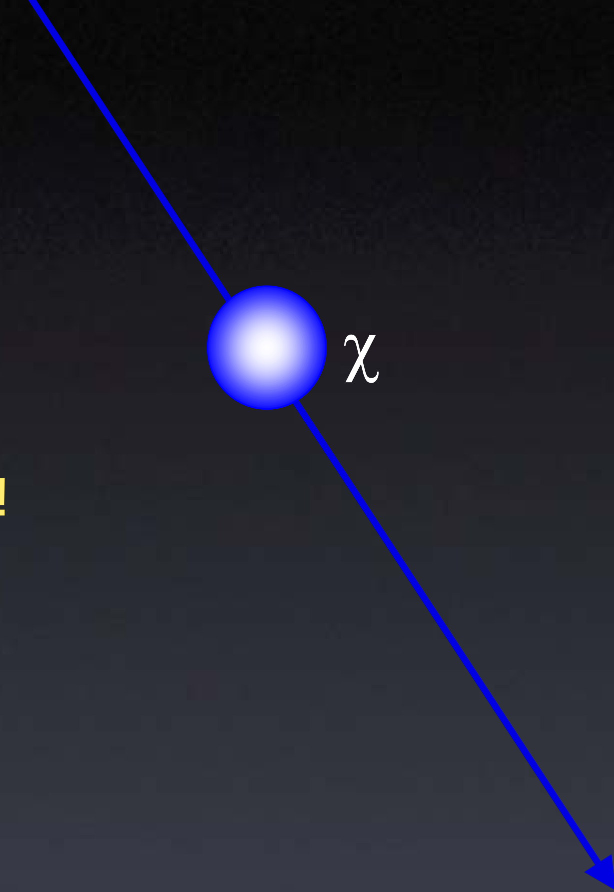
Gravitational lensing



Hubble image of gravitational lensing around Abell 2218 (NASA)



Weakly Interacting Massive Particles



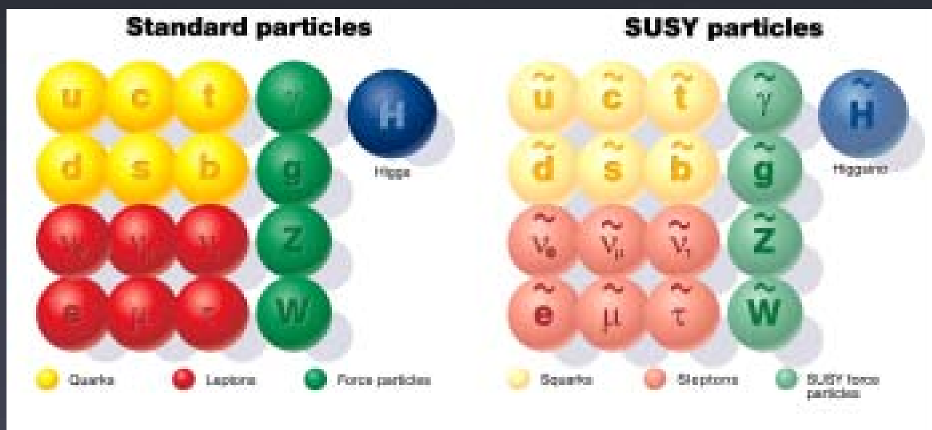
A WIMP χ is like a massive neutrino…

Produced in the Big Bang

Is very long-lived or stable

Interacts very weakly: can travel through Earth without stopping!

Is predicted in Supersymmetry theory of particle physics:



Lightest particle, with a mass ~ 100 x proton mass, is called the **neutralino**

Has exactly the right properties to be the dark matter!

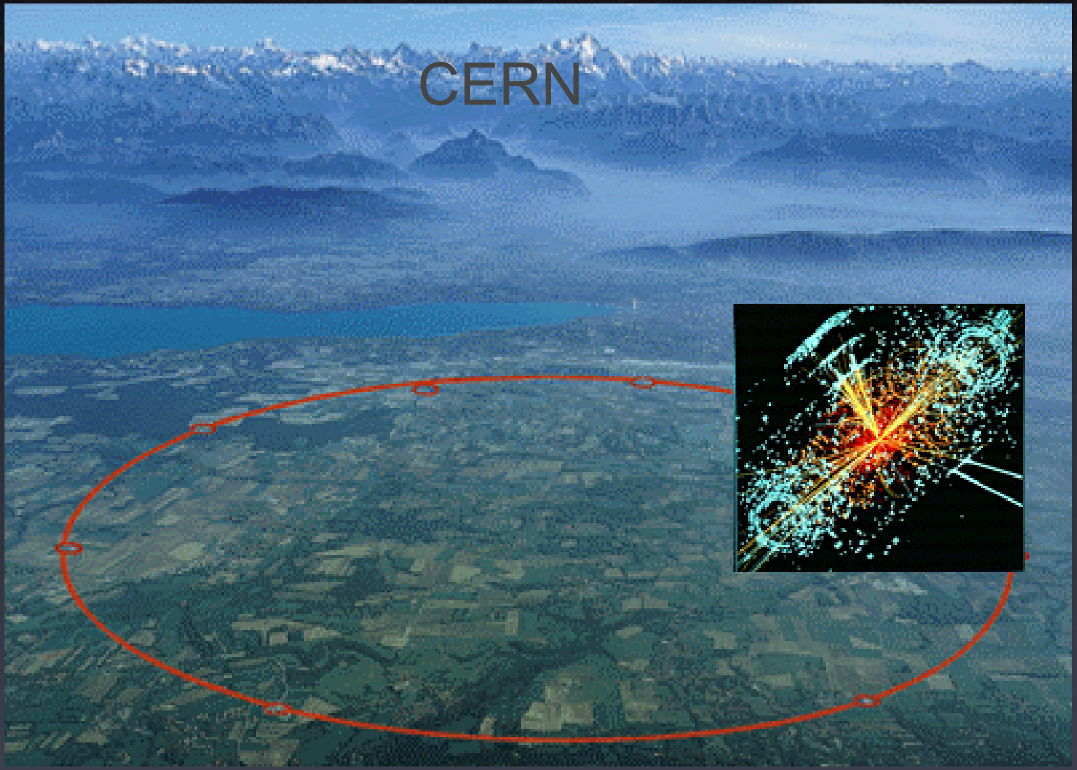
WIMPs:

Every liter of space: 10-100 WIMPs, moving at 10^{-3} the speed of light

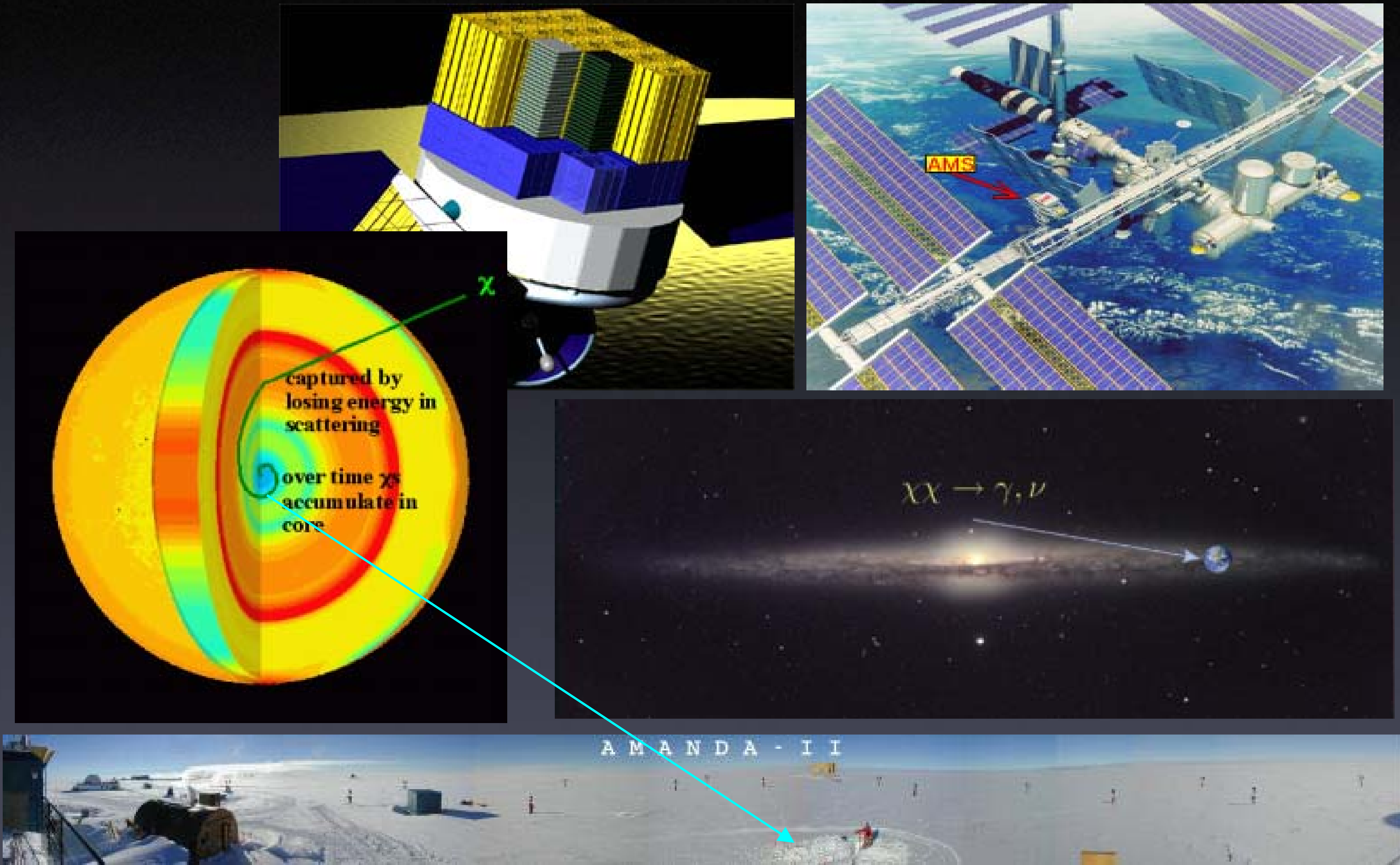
10^{15} through a human body each day: only < 10 will interact, the rest is passing through unaffected!

If their interaction is so weak, how can we detect them???

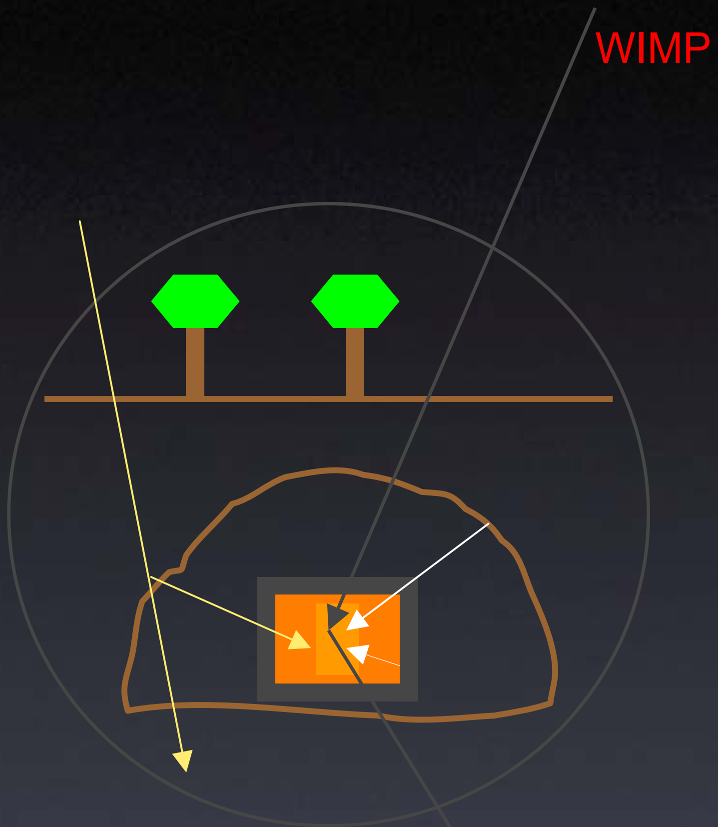
We can make them in accelerators…



We can look at the Sun or go into space…



…or we can go to an underground lab and directly detect WIMPs



Direct Detection:a challenging task

Rate: 10^{-1} - 10^{-5} /kg/day

Nuclear recoil energy: 10 - 100 keV

Very large background: gamma rays and neutrons from radioactivity and cosmic rays

WIMPs scatter elastically with nuclei:

Rate ~ N ρ_χ / m_χ $\langle\sigma_\chi\rangle$

N = number of target nuclei in detector

ρ_χ = local WIMP density

$\langle\sigma_\chi\rangle$ = scattering cross section

From the density of dark matter in the galaxy:

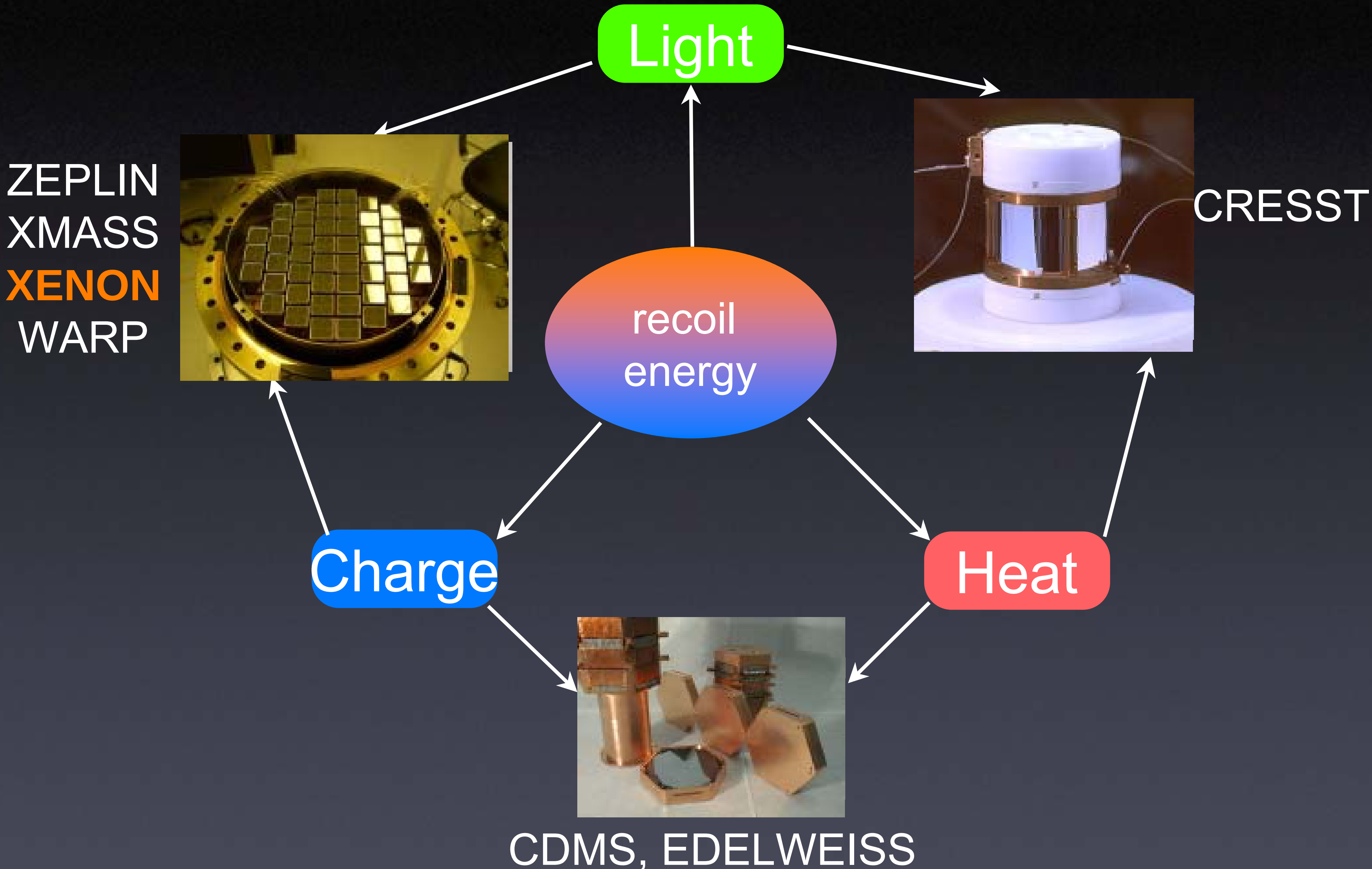
Every liter of space: 10-100 WIMPs, moving at 1/1000 the speed of light

=> Less than 1 WIMP/week will collide with an atom in 1kg material

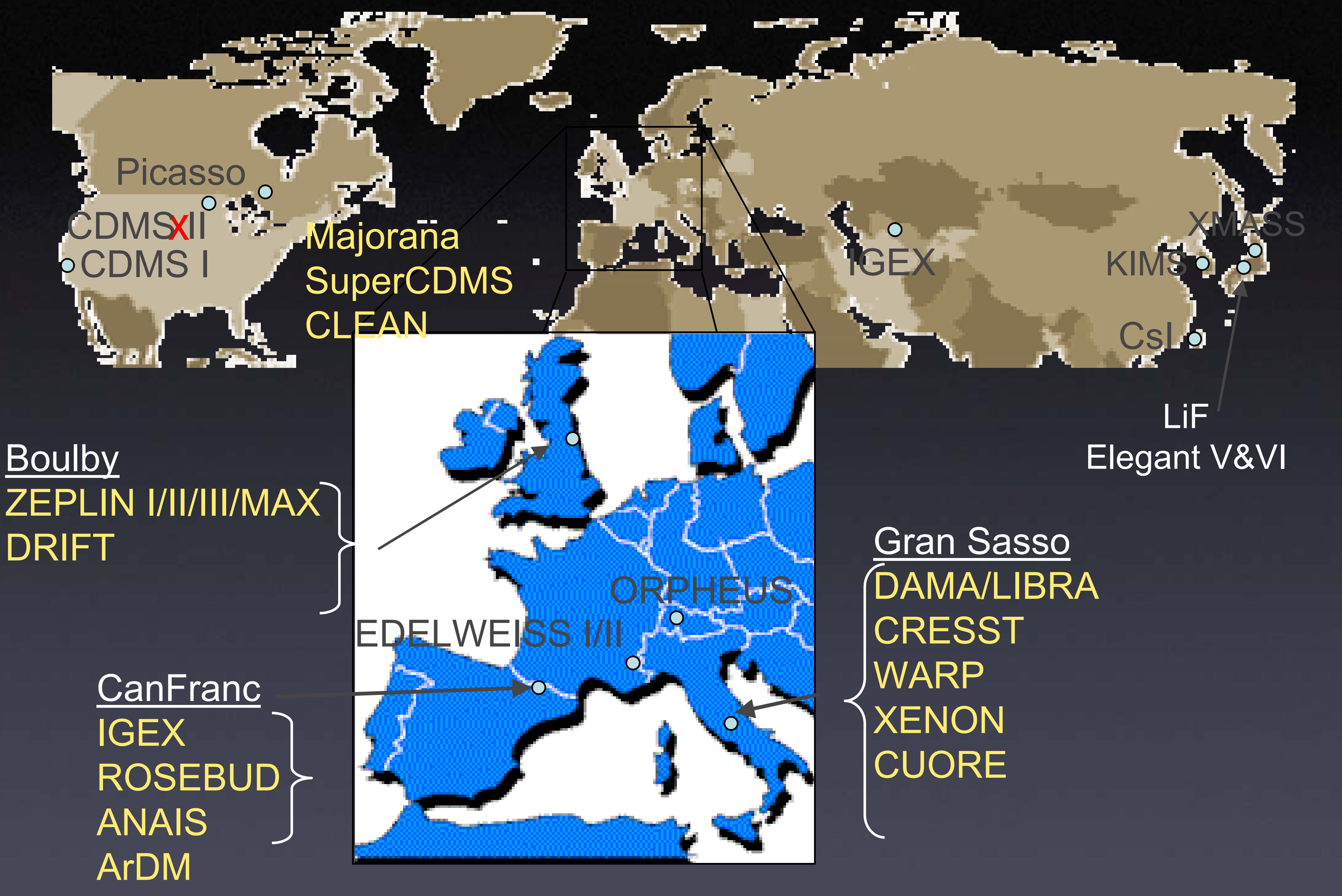
Detectors must effectively discriminate between

Nuclear Recoils (Neutrons, WIMPs)

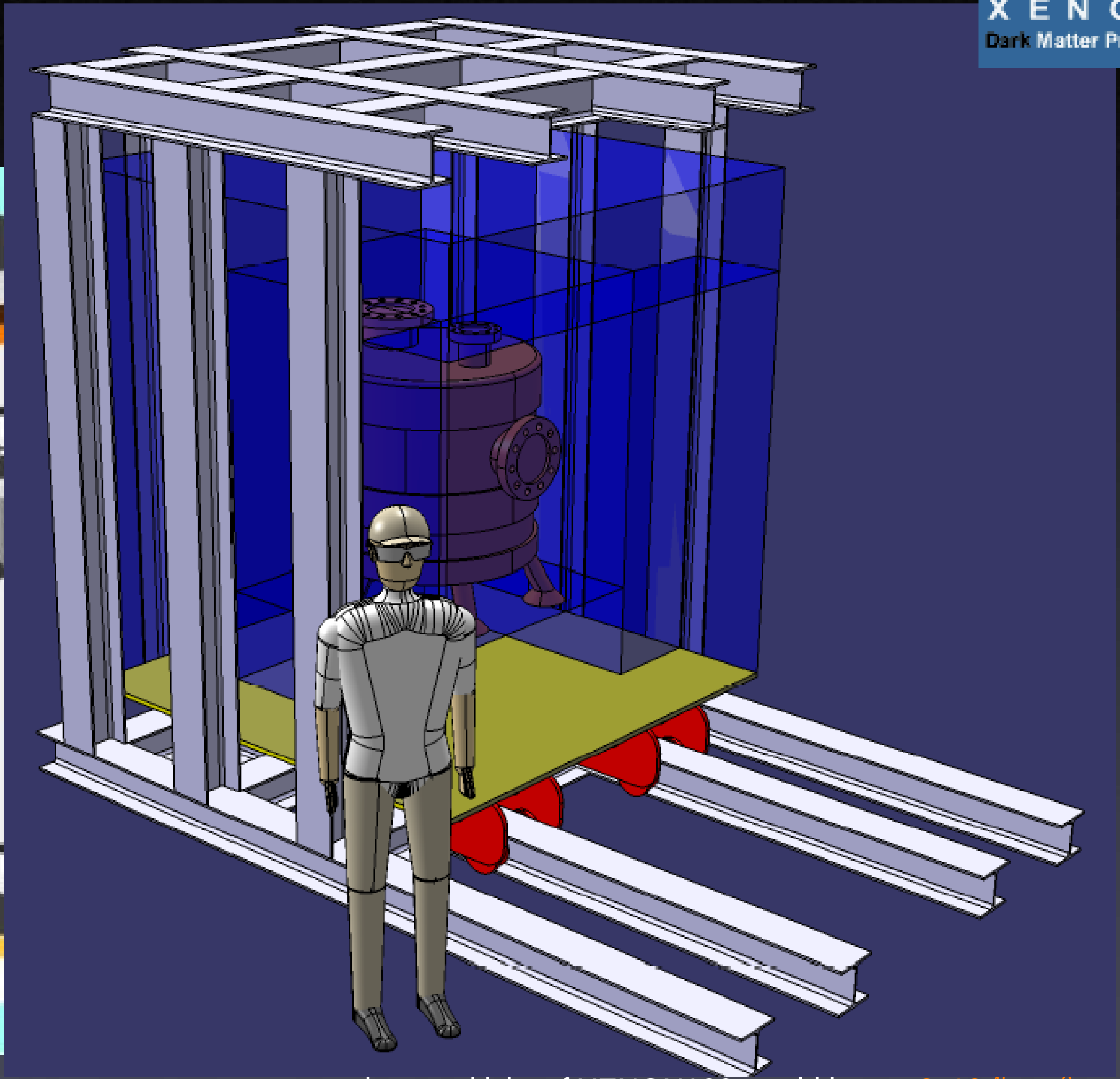
Electron Recoils (gammas, betas)



World Wide WIMP Search



The XENON Experiment: Overview



the sensitivity of XENON100 would be $\sigma \sim 2 \times 10^{-45}$ cm^2 .

XENON Dark Matter Goals

- XENON10 (2006-2007):

10 kg target ~2 events/10kg/month

Equivalent CDMSII Goal for mass >100 GeV
(Current CDMS limit is 10 x above this level)

Important goal of XENON10 underground is to establish performance of dual phase TPC to design optimized XENON100

- XENON100 (2007-2008):

100 kg target ~2 events/100kg/month

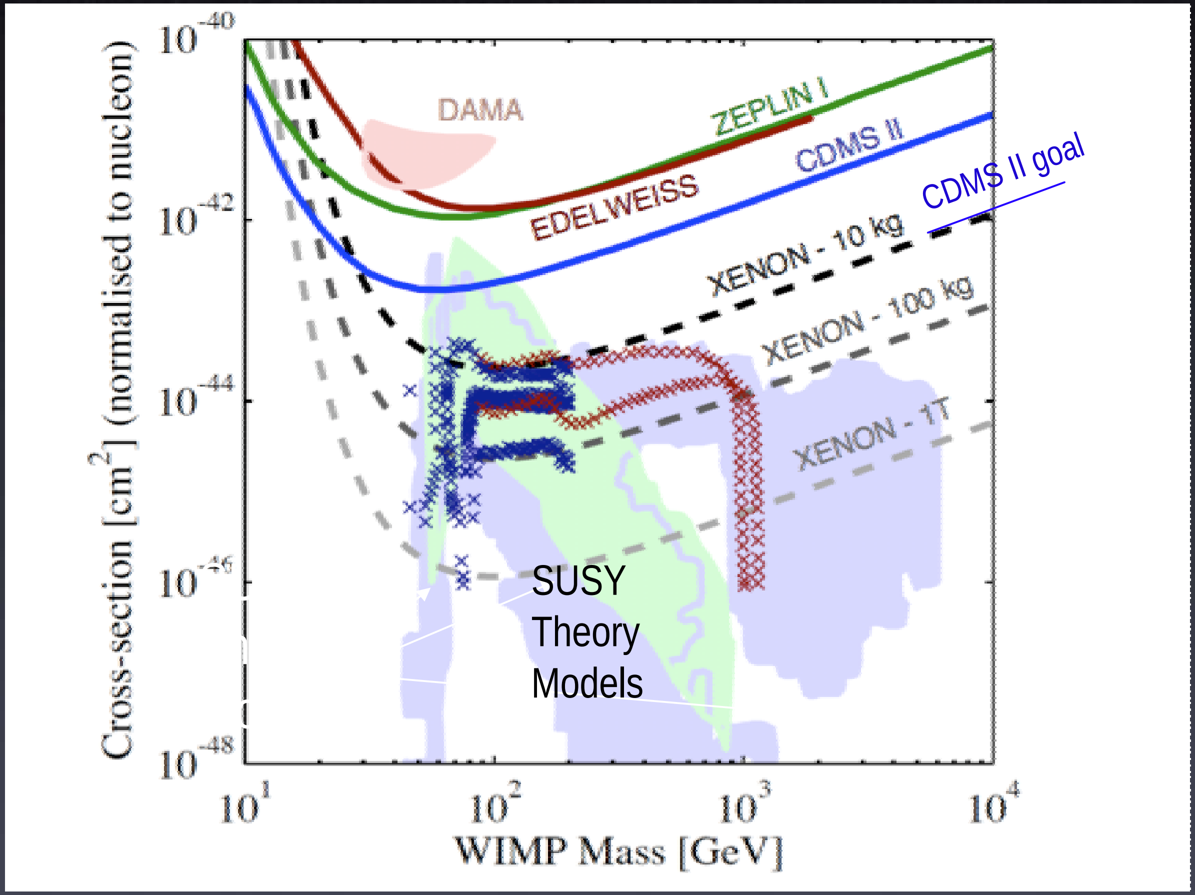
- XENON-1T (2008-2012?):

1 ton (10 x 100 kg modules)

10^{-46} cm^2 or ~1 event/1 tonne/month

Test majority of SUSY models.
Discover Dark Matter!

Dark Matter Data Plotter
http://dmtools.brown.edu



Why Liquid Xenon?

High atomic mass (A ~ 131): favorable for SI case ($\sigma \sim A^2$)

Odd isotope with large SD enhancement factors (^{129}Xe, ^{131}Xe)

High atomic number (Z=54) and density ($3 g/cm^3$)
=> compact, self-shielding geometry

'Easy' cryogenics at -100 C

No long-lived radioisotopes

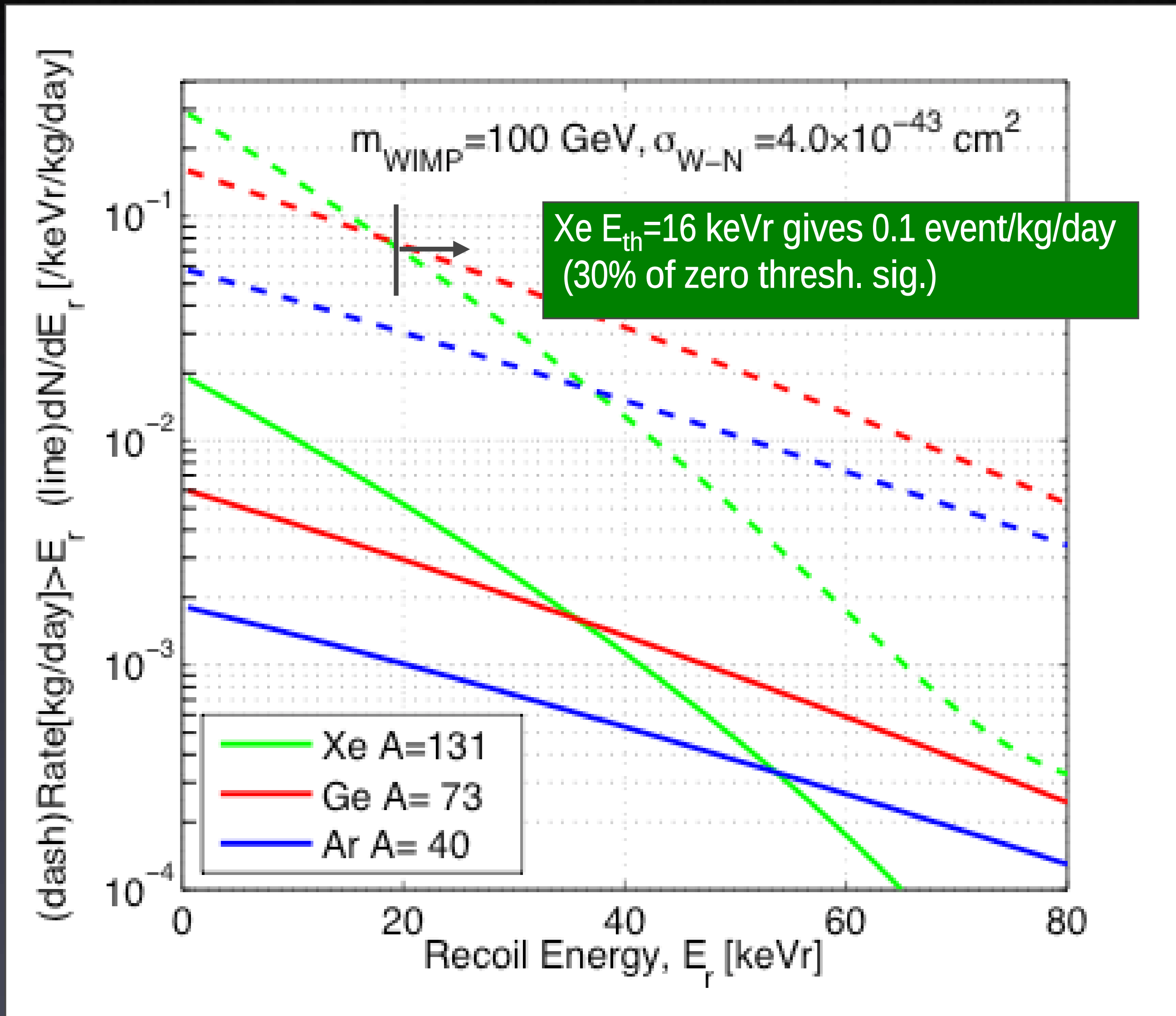
Excellent Scintillator (~NaI(Tl)) and Efficient Ionizer (W=15.6 eV)

Simultaneous Light and Charge Detection => background discrimination

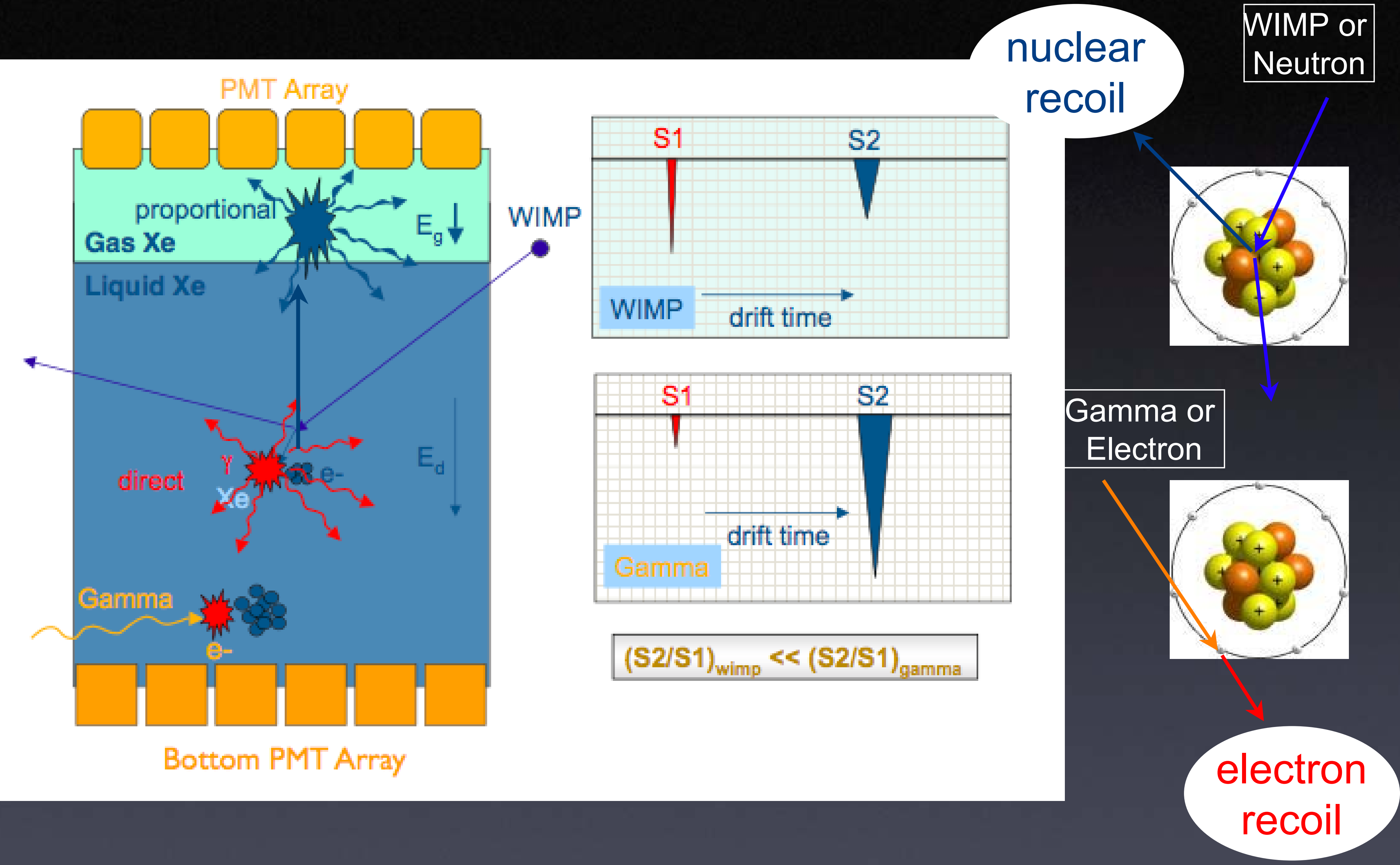
Very Typical WIMP Signal in Xe

Xe rate enhanced by high A, but low threshold necessary to avoid Form Factor suppression

$$\int_{E_r}^{\infty} \frac{dN}{dE}$$



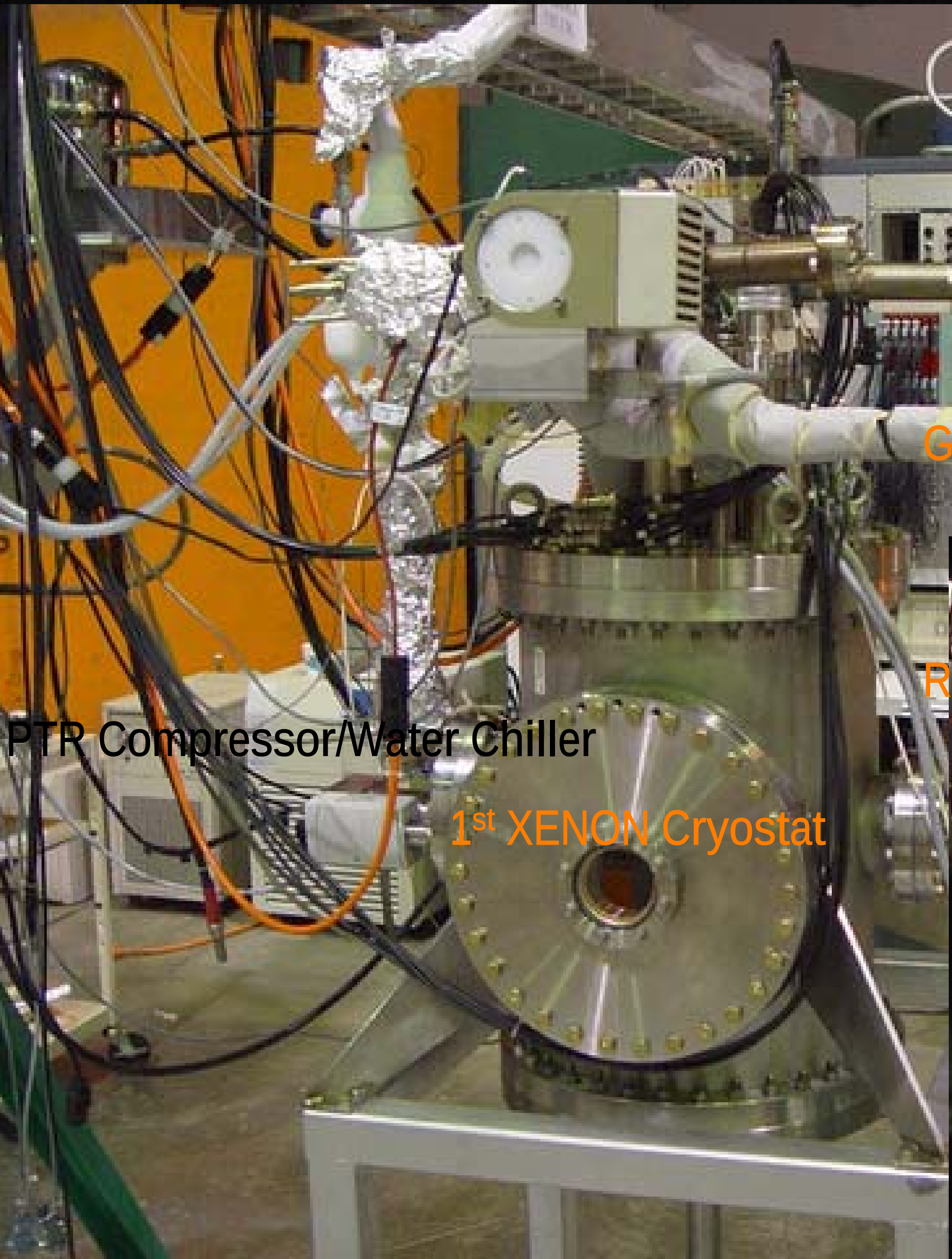
Principle of Operation

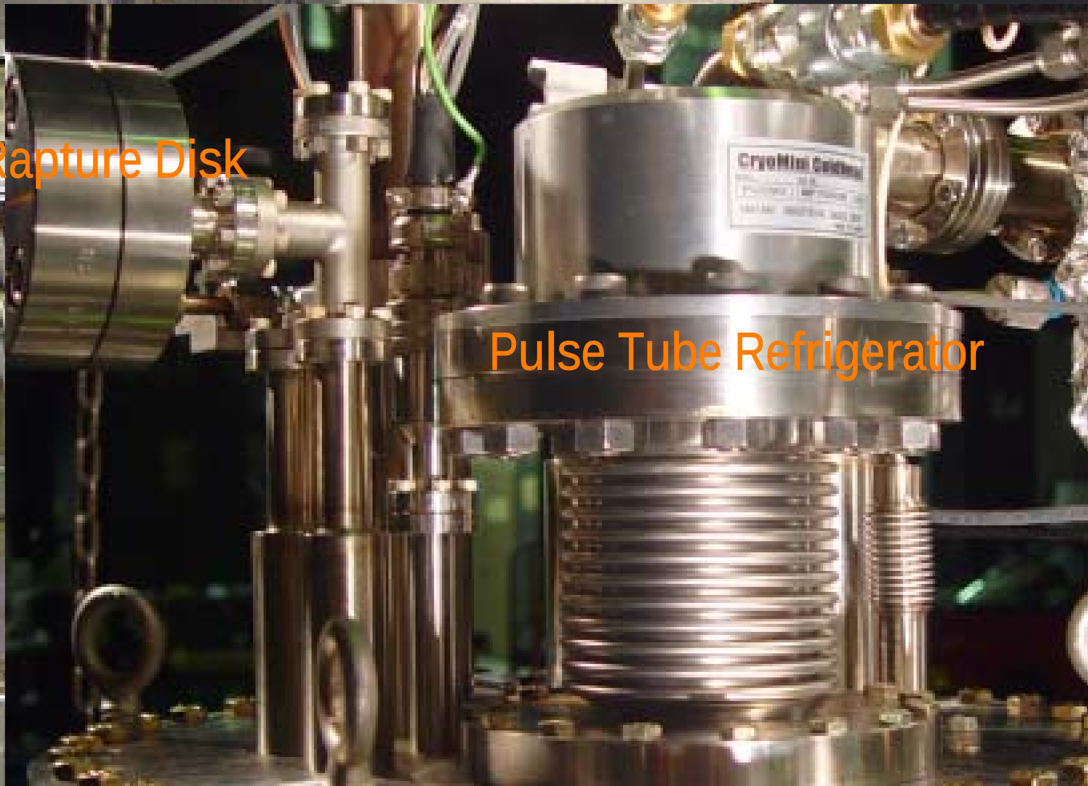


XENON R&D Goals: Summary

+ PMTs operation in LXe	Achieved
+ > 1 meter L_e in LXe	Achieved
+ Operating ~1 kV/cm electric field	Achieved
+ Electron extraction to gas phase	Achieved
+ Efficient & Reliable Cryogenic System	Achieved
+ Nuclear recoil Scintillation Efficiency (10-55 keVr)	Achieved
+ Nuclear recoil Ionization Efficiency	Achieved
+ Electron/Nuclear recoil discrimination	Achieved
+ Kr removal for XENON10	1 kg purification achieved
+ Electric Field / Light Collection Simulations	Tools Developed_Done for XENON10
+ Background Simulations	Tools Developed_Done for XENON10
+ Materials Screening for XENON10	All major components screened
+ Assembly of XENON10 System	Achieved
+ Low Activity PMTs and Alternatives Readouts	Verified Hamamatsu #'s

XENON3/10 Set-Up at Columbia Nevis Lab





Recent Highlights from XENON R&D

LXe Scintillation Efficiency for Nuclear Recoils

- The most important parameter for DM search
- No prior measurement at low energies

  Aprile at al., Phys. Rev. D 72 (2005) 072006

LXe Ionization Efficiency for Nuclear Recoils

- XENON (and other LXe concepts) rely on WIMP identification by simultaneous detection of recoil ionization and scintillation
- No prior information on the ionization yield as a function of energy and applied E-field

  Aprile et al., PRL (2006), astro-ph/0601552

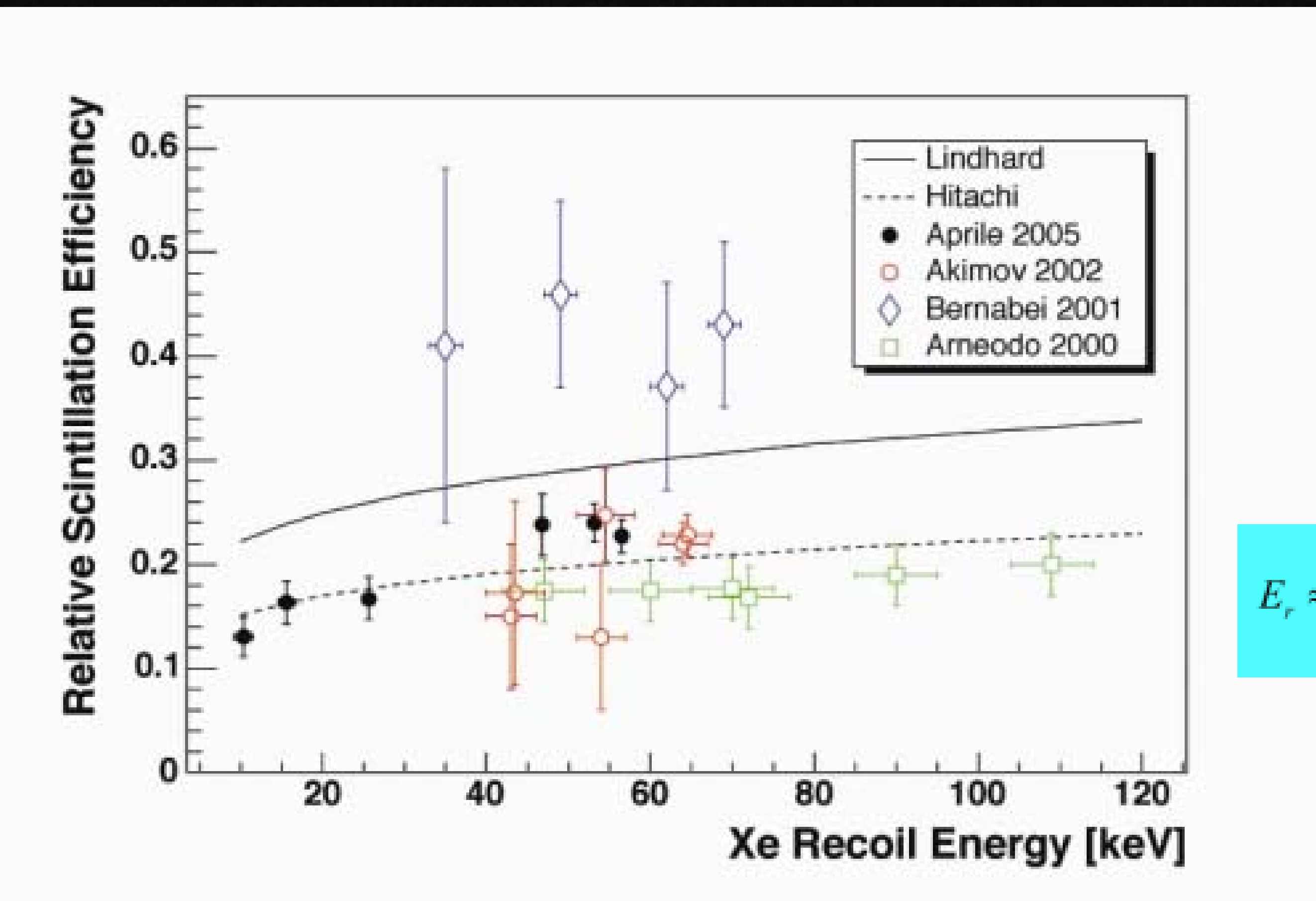
Development of XENON10 Experiment for Underground Deployment

- Validate Cryogenics, HV, DAQ systems with 6kg prototype
- Demonstrate low energy threshold/discrimination and position reconstruction with neutron and gamma calibration sources

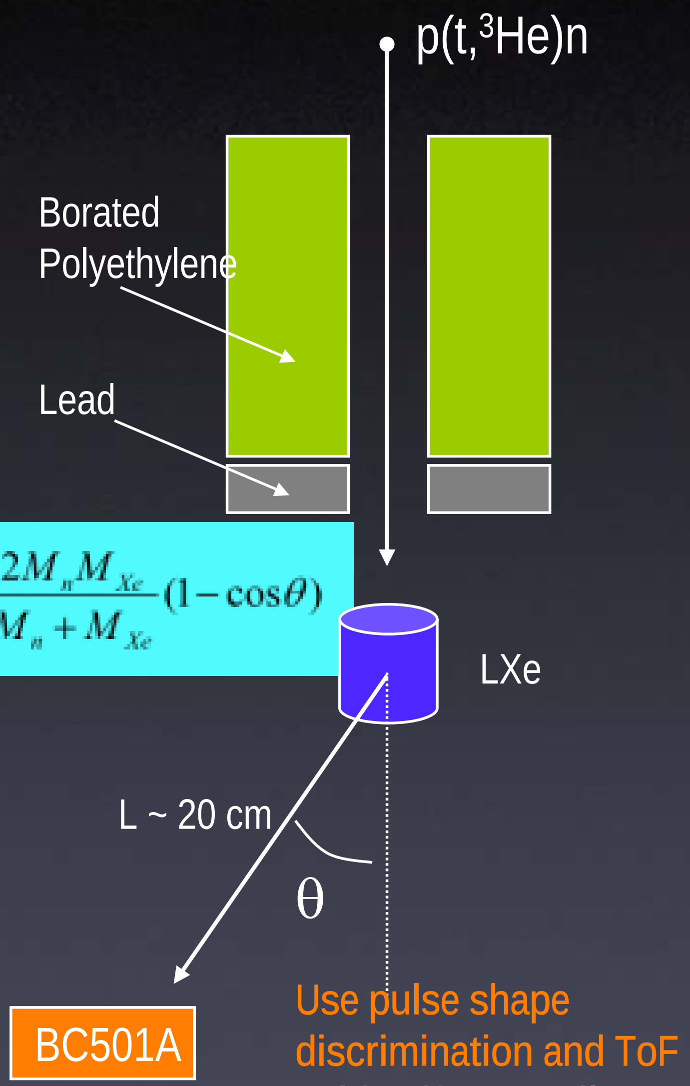
Xe-Recoils Scintillation Efficiency

[Columbia and Yale]

Columbia RARAF
2.4 MeV neutrons



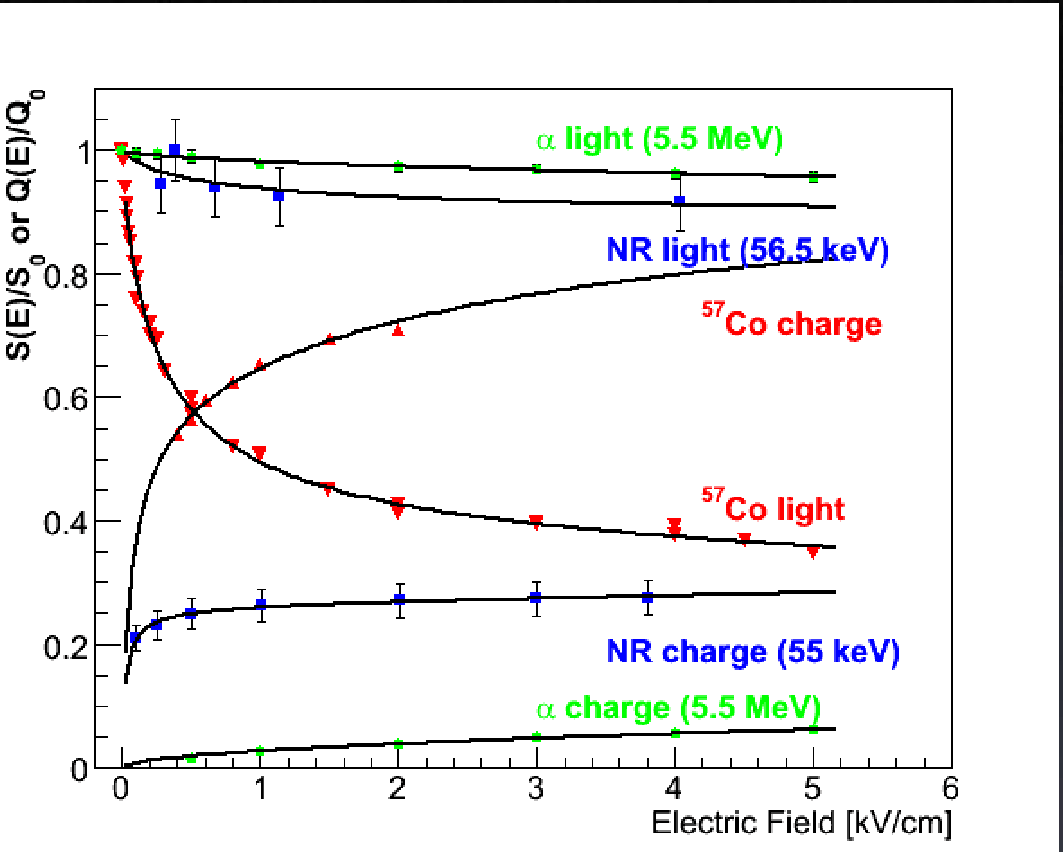
Aprile et al., Phys. Rev. D 72 (2005)

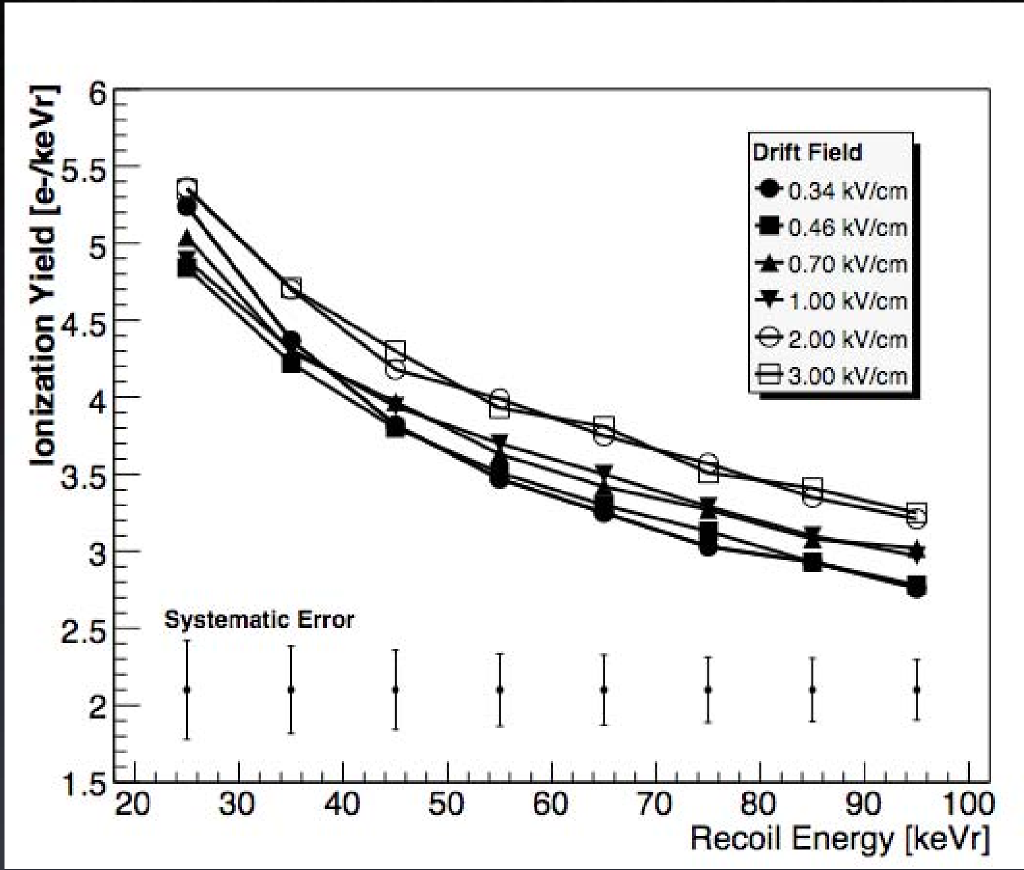


$$E_r \approx E_n \frac{2M_n M_{Xe}}{M_n + M_{Xe}}(1-\cos\theta)$$

Use pulse shape discrimination and ToF to identify n-recoils

Xe-Recoils Ionization Yield

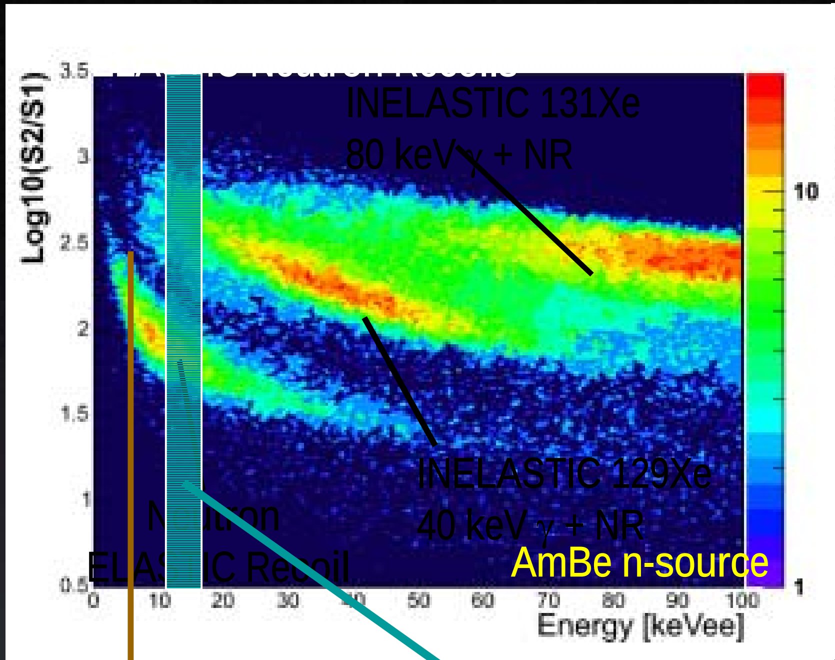


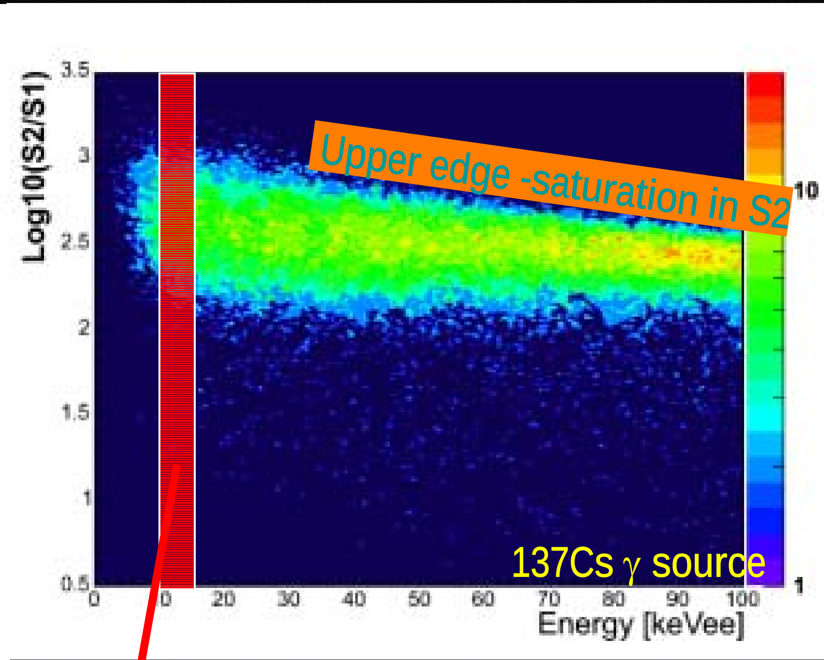


- 1st Measurement of the charge of low energy recoils in LXe and of the field dependence.
- Charge yield surprisingly higher than expected and with very weak field dependence.

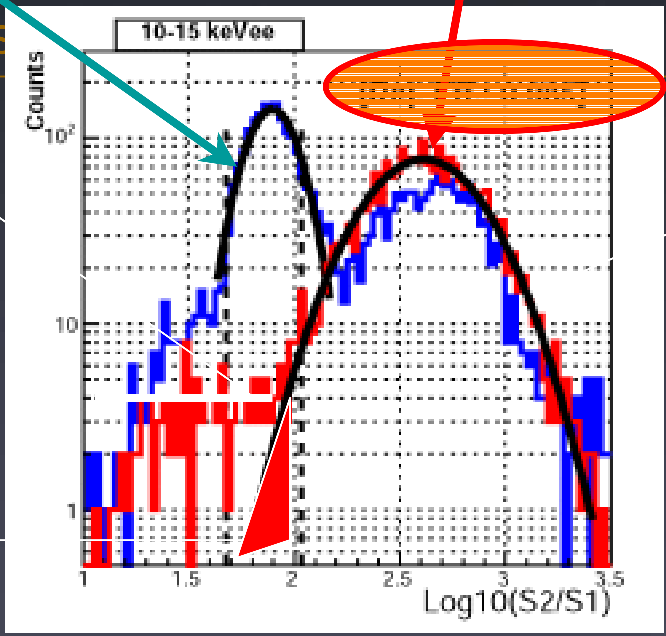
[Columbia, Brown and Case]

Background discrimination capability





5 keVee energy thres... l



γ leakage mainly from edge events

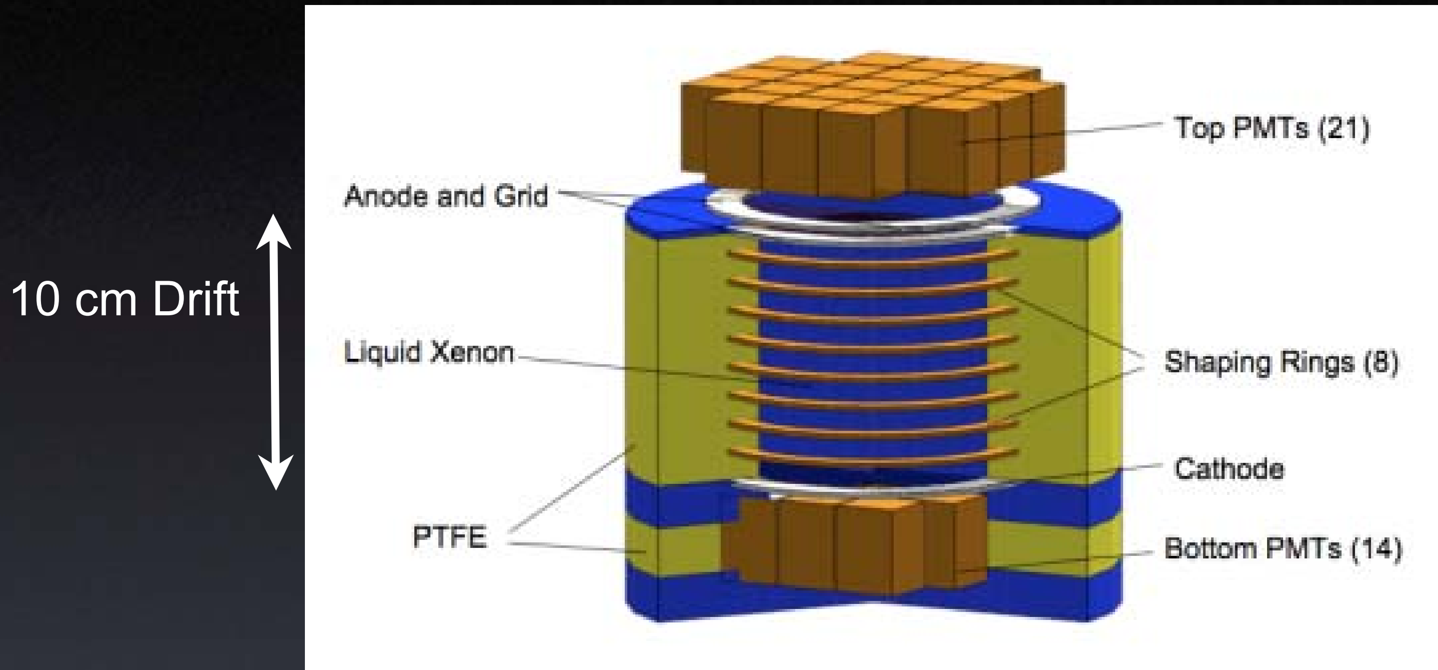
Gaussian fit

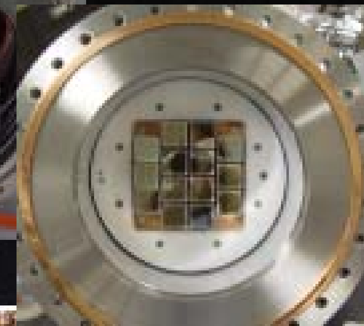
improvement expected by XY position cut with a 3D detector

80% NR acceptance [-1.65σ, 1 σ]

XENON3: the first 3D sensitive dual phase xenon detector

Hamamatsu R8520 PMT:
Compact metal channal: 1 inch square x 3.5 cm
Low background: 3 mBq
Quantum Efficiency: >20% @ 178 nm





why we need 3D sensitivity?

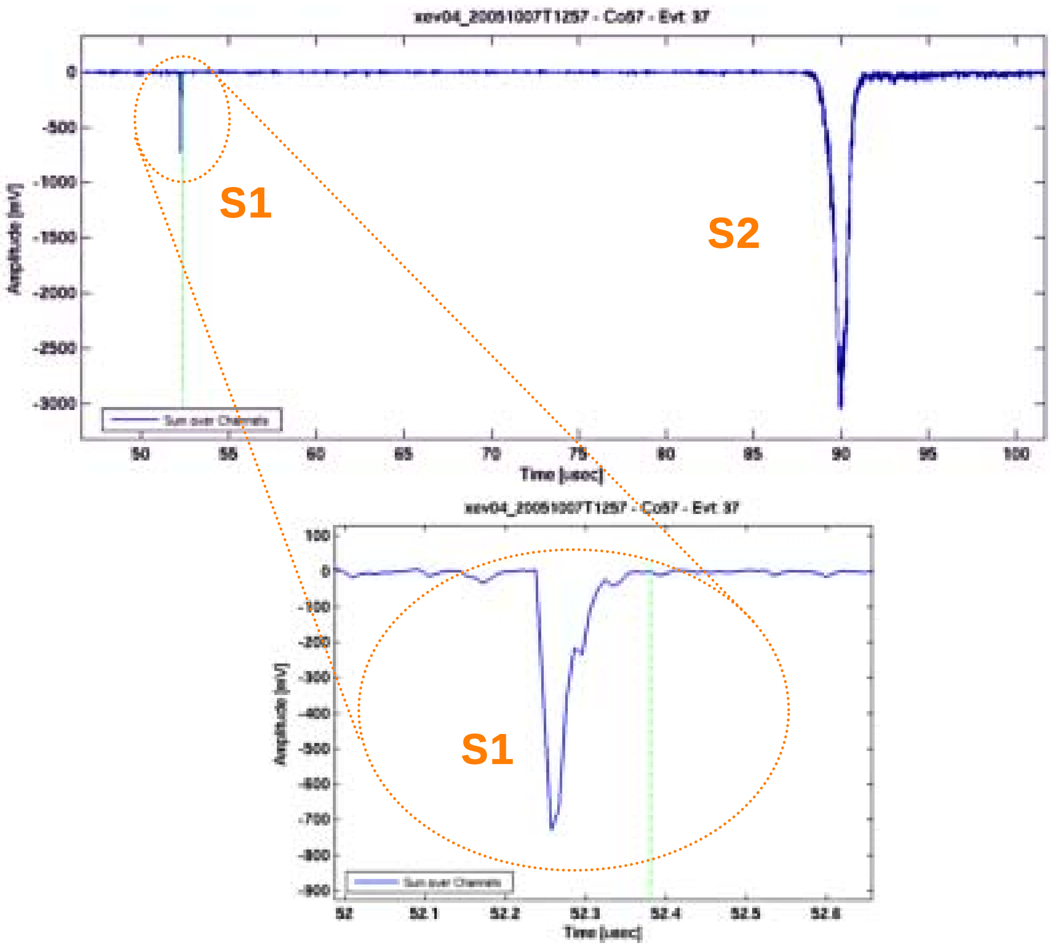
- background events occur mostly near edge (maximum r) and surface (top/bottom) → efficiently reduce them by fiducial volume cut
- electric field lines near the edge are not uniform and straight → edge/surface events mimic nuclear recoils and have to be removed
- unlike WIMPs, neutrons multiple-scatter in the detector → knowing event positions can further reduce backgrounds

XENON3 TPC response to neutrons (^{252}Cf) and gammas (^{57}Co)

Electric Field = 1.0kV/cm

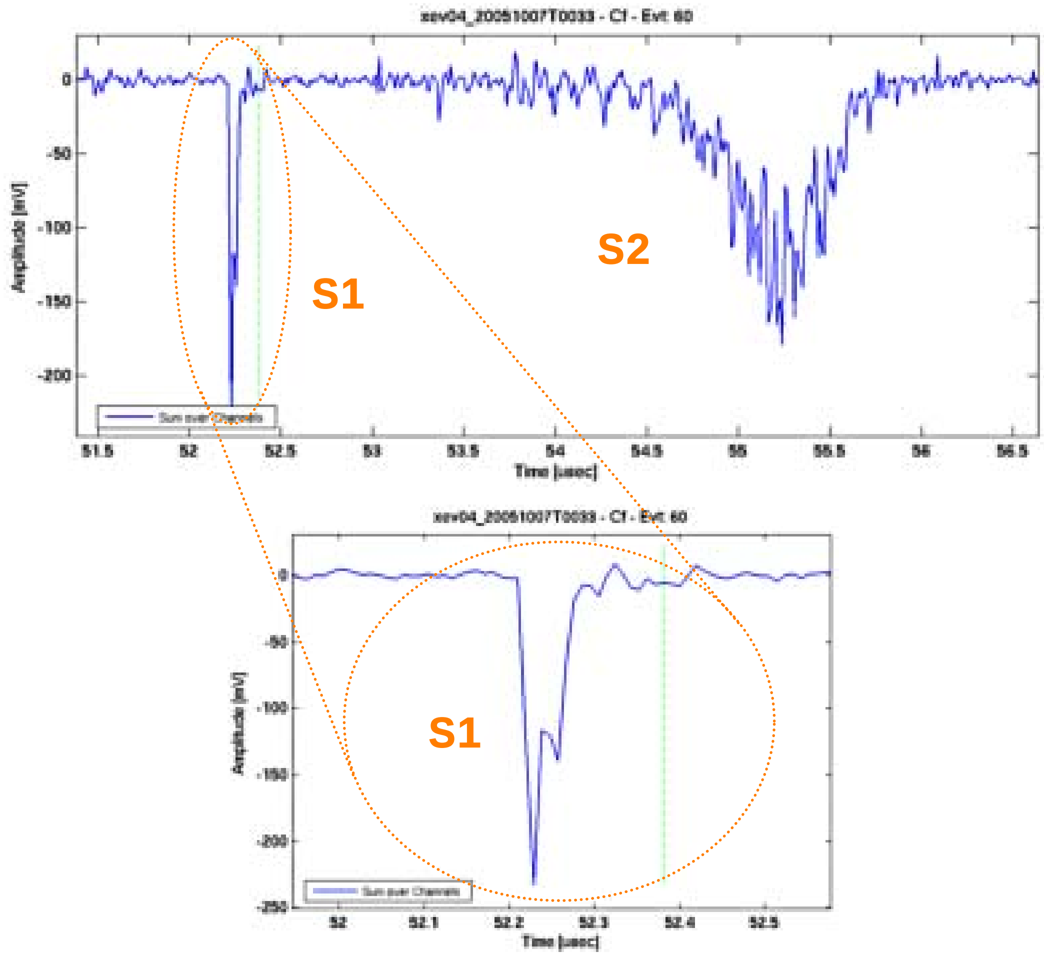
<u>Gamma event</u>

S1 = 180 phe ~ 180keVee

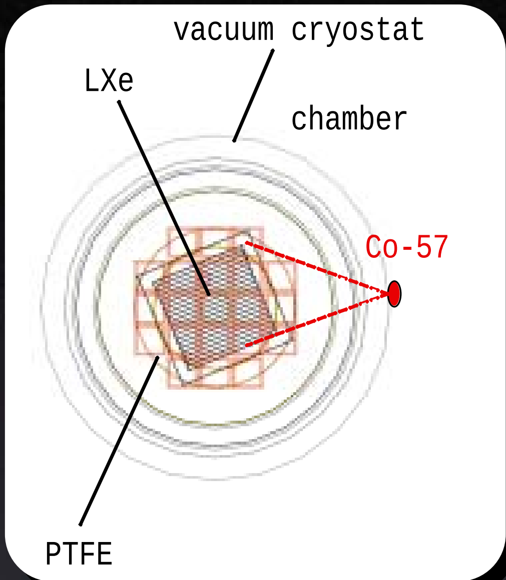


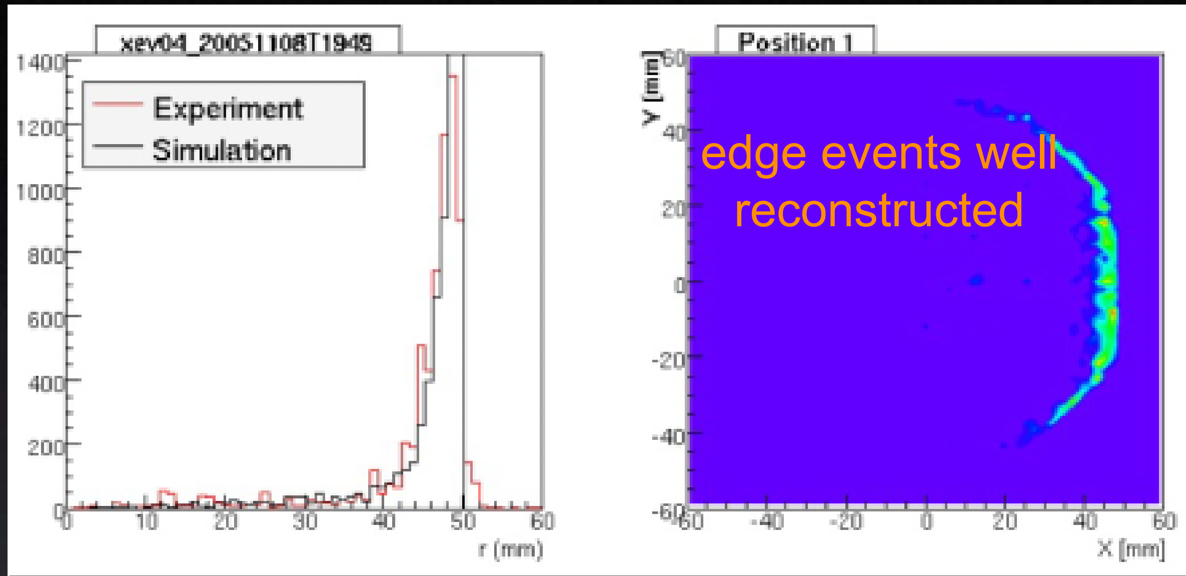
<u>Nuclear Recoil event</u>

S1 = 70 phe ~ 70keVee



XENON3 Position Reconstruction



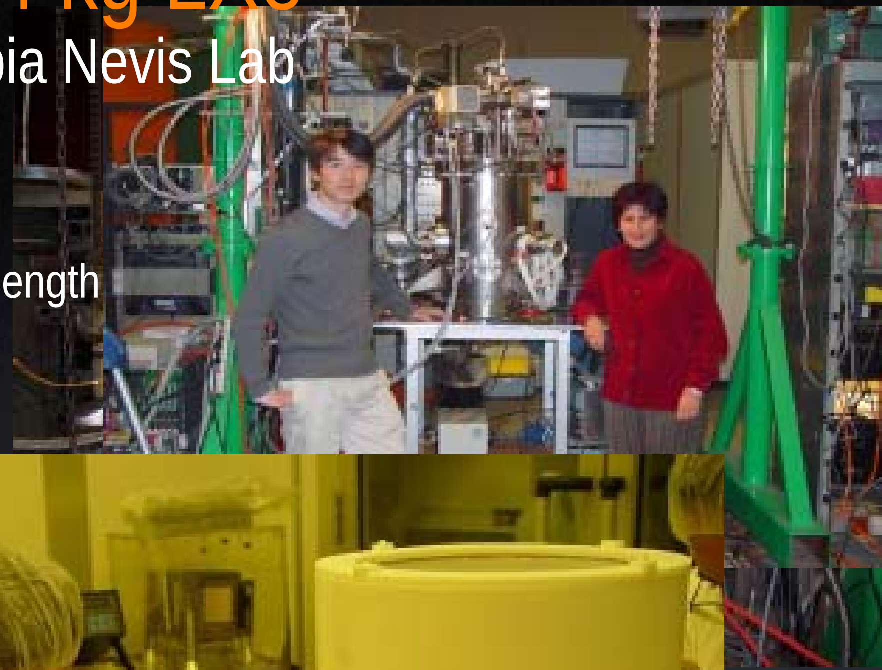


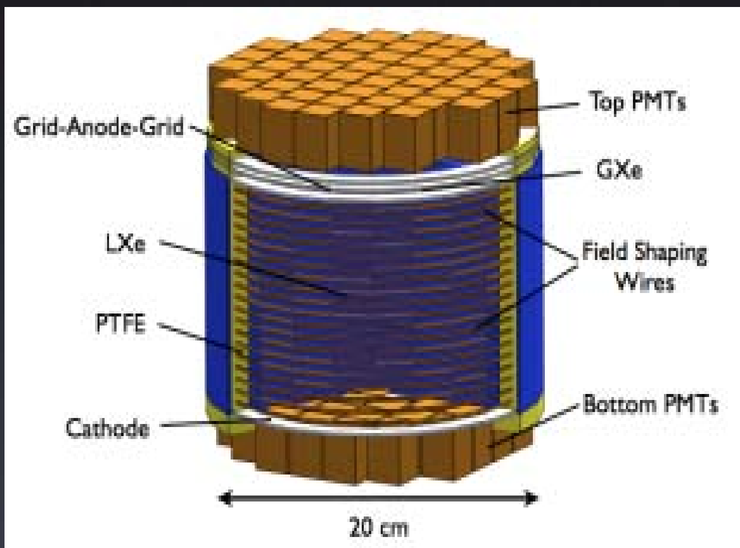
Preliminary Algorithms already achieving <1 cm position resolution.
Simulations suggest σ_{xy}~2 mm should be possible at 20 keVr.

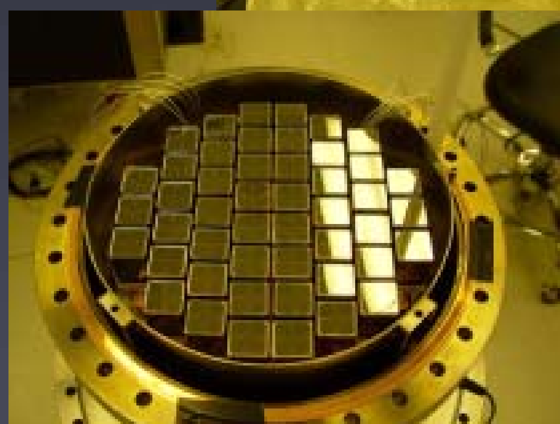
[Kaixuan Ni, Columbia]

XENON10 TPC with 14 kg LXe

- XENON10 now running above ground at Columbia Nevis Lab
  - Testing prior to shipping to LNGS
  - 48 PMTs on top, 41 on bottom, 20 cm diameter, 15 cm drift length
  - 22 kg needed to fill the TPC. Active volume ~14 kg.





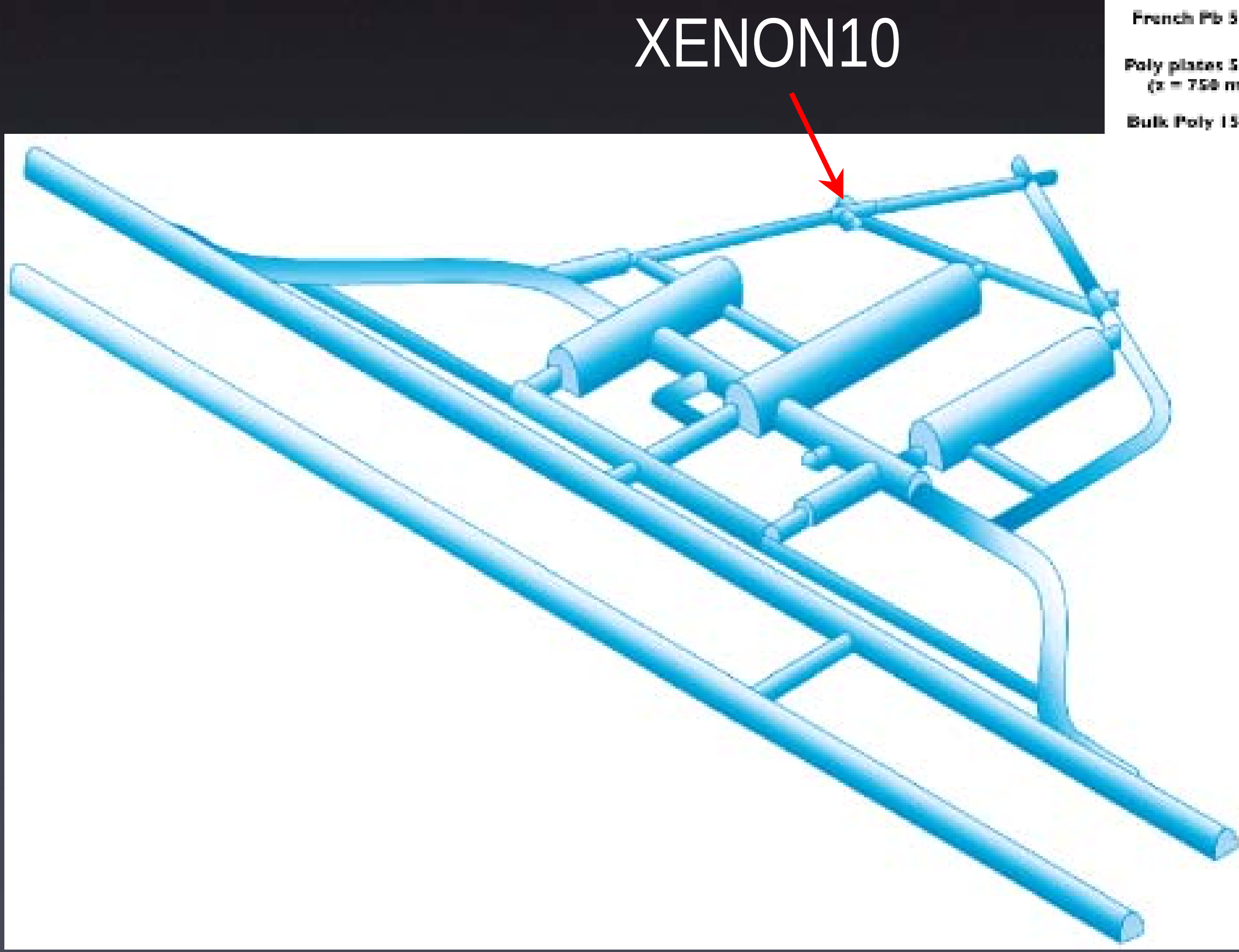


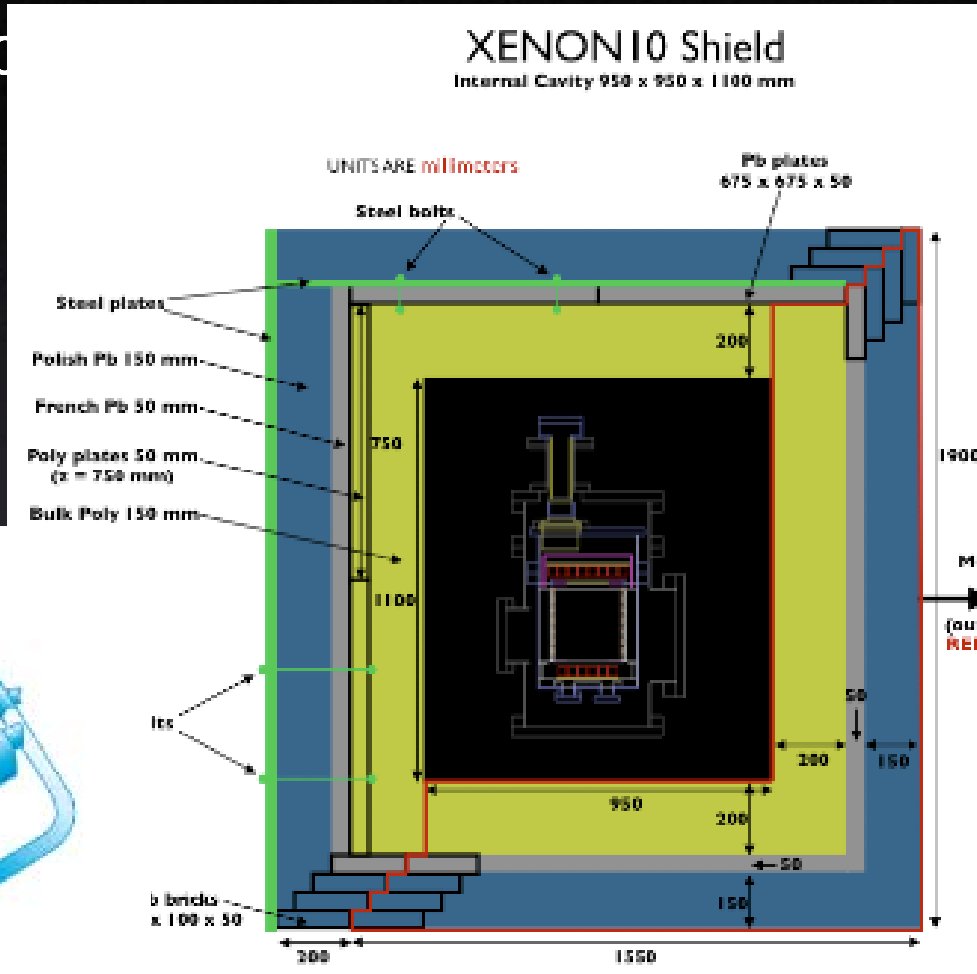
[Masaki Yamashita, Columbia]


Vacuum
Gauge

XENON10 at LNGS: Gran Sasso National Laboratory

Ex-LUNA Building 5 x 7 m (4 m H) Detecto
+ 2.5 x 8 m Box Assembly Space
+ 2.5 x 6 m Box Analysis

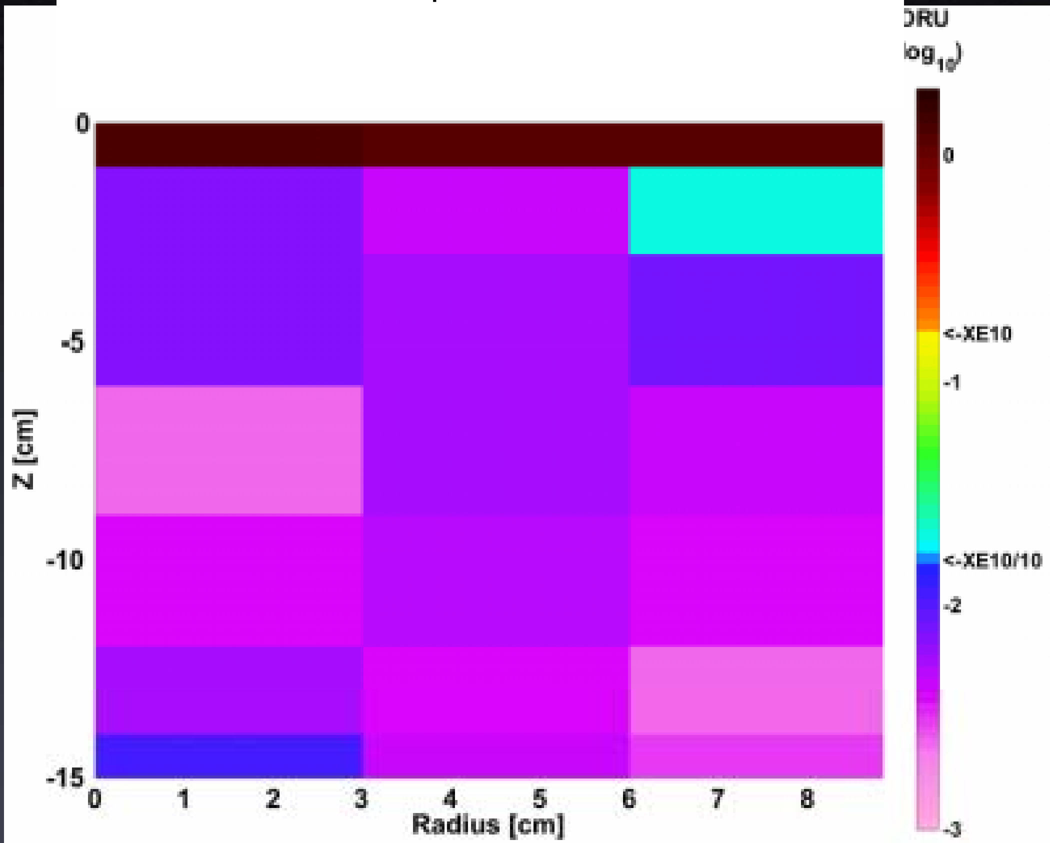




XENON10 “Intrinsic” Backgrounds

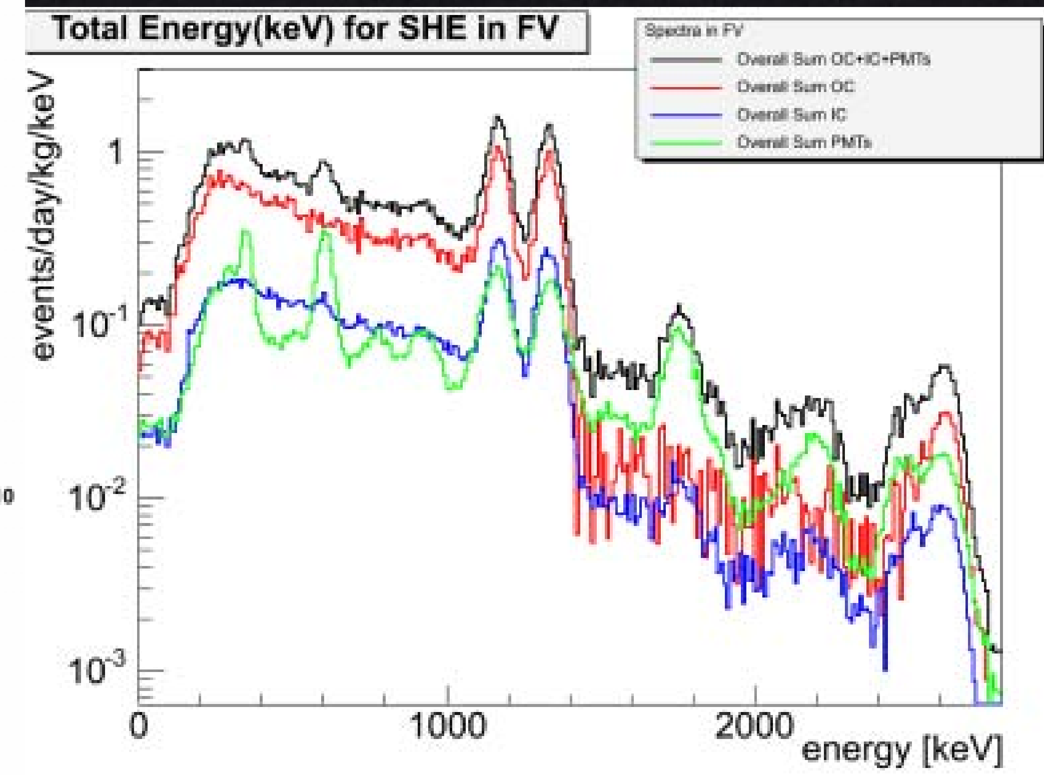
dru == /keV/kg/day

Event Rates 10-50 keVee
Hamamatsu R8520 <3 mBq/PMT



[Luiz de Viveiros, Brown]

Stainless from inner + outer vessel + PMT
0.11 dru in 10.3 kg fiducial LXe 0-50 keVee
(17.3 kg gross volume)



[Joerg Orboeck, U. FLORIDA]

Space: **Underground Lab Requirements for XENON100-1T**

6m x 6m x 7 m (H) experimental room for XENON100 with conventional shielding.

14m x 12m x 7m (H) for ten XENON100 modules with conventional shield. 5 ton crane . Chilled Water. Ventilation. AC-control.

16m x 11m x 15 (H) for XENON1T with a water shield

A LAr active shield is also being considered for XENON1T

Experimental area: Class 2000. Adjacent Detectors Assembly Clean Room:Class 100 C

Radon Background < 100 mBq/m^3

Additional underground space ~150 m^2 : Xe gas handling/purification/cryogenics/electronics/control/analysis

Machine Shop/Mechanical Electrical Engineering support/Radiation Safety/Sources/Chemicals Storage

Electrical Power:

200 kW peak; 100kW average + UPS (20 kW)

Compressed Gases/Cryogens:

Nitrogen/He/Xe Gases; Liquid Nitrogen: 100 l/week for 100 kg module; Kr-removal Purification Plant

Above ground office space:

Collaboration size ~50 physicists. Occupancy 15 people peak/5 people steady

Safety Issues for XENON Underground

- XENON only uses a liquefied noble gas, mechanical equipment, electronics, and a standard or water shield for neutrons. No flammable, toxic, or hazardous chemicals.
- During operation the liquid xenon is kept at about –100 C (P~2 atm) by a mechanical refrigerator. The liquid is contained in a double walled stainless steel cryostat.
- In case of refrigerator failure, or prolonged power failure, LN cooling is automatically initiated. We note that the heat capacity of LXe and the superinsulation of the detector cryostat are such that it will take very long time to evaporate Xe. Risk of asphyxiation by Xe release in the cavern, even in catastrophic scenario is minor.
- In case of failure of LN cooling system, a pressure rise to 3 atm would burst a safety rupture disc, releasing the overpressure into a bladder system to recover the Xe gas.